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TITLE - Atmospheric Contamination in
the AAP Cluster Due to Gaseous
Products of Human Metabolism

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ABSTRACT

The continual excretion of gaseous waste by humans introduces a source of atmospheric contamination that may be an appreciable factor in AAP Missions A and B (AAP 1-4). This memorandum considers contaminant generation by the crew, removal mechanisms intentionally or inherently present in the current Cluster design, and requirements for additional removal mechanisms from the standpoint of physiological effects.

It is concluded that carbon monoxide concentrations, based on generation rates measured by Gorban et al (1964) and CO removal by nominal atmospheric leakage, may be excessive when compared with recommended maximum concentrations for chronic exposure to CO.

A strategy for controlling CO contamination of the Cluster atmosphere therefore appears to be desirable. Available alternatives include one or more of the following: Provision of more O₂/N₂ to permit higher leak rates and, thus, lower CO equilibrium concentrations; provision of CO sensors together with cabin-dump or mission abort criteria; provision of a catalytic burner; reliance on nominal Cluster leakage for CO removal; or some combination of these approaches. Detailed study is required to determine the optimum strategy for dealing with the CO contamination hazard as well as the possible hazards arising from other atmospheric contaminants.

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BELLCOMM, INC.

SUBJECT: Atmospheric Contamination in the
AAP Cluster Due to Gaseous
Products of Human Metabolism -
Case 620

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FROM: D. J. Belz

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TECHNICAL MEMORANDUM

1.0 INTRODUCTION

Gaseous contamination of cabin atmospheres is a source of concern in the design of manned spacecraft for two reasons: Prolonged exposure to certain gases may produce toxic reactions in the crew; combustible gases in sufficient quantities may create a fire or explosion hazard within the vehicle.

Sources of contamination include leakage of stored fluids, outgassing of nonmetallic materials in equipment throughout the cabin, and gaseous products given off by the crew. Outgassing of equipment and leakage of fluids can be minimized although not eliminated by careful design and selection of materials; metabolic contamination of manned spacecraft atmospheres is, however, unavoidable.

The continual excretion of gaseous waste by humans through respiration, expulsion of colonic flatus, and the volatile breakdown of sweat renders atmospheric contamination peculiarly sensitive to mission duration as well as contaminant removal mechanisms. Gemini 7, the longest manned spaceflight to date, had a mission duration of a little less than fourteen days. Beginning with the early flights of the Apollo Applications Program, mission durations of 28 days (AAP-1/AAP-2) and 56 days (AAP-3/AAP-4) will be attempted. The unprecedented duration of these missions provides an incentive to study the role of the crew in contributing to cabin atmospheric contamination. This memorandum considers contaminant generation, removal mechanisms intentionally or inherently present in the current Cluster design, and requirements for additional removal mechanisms from the standpoint of physiological effects.

2.0 PRODUCTION OF GASEOUS CONTAMINANTS BY MAN

Qualitative and quantitative studies of gaseous products given off by man have been undertaken by relatively few authors. Kirk (Reference 1) has measured the quantity and composition of human colonic flatus and has compared his findings with four prior

studies conducted between 1862 and 1943; in order of descending abundance he identified the components of colonic flatus resulting from a cabbage-free but otherwise "ordinary" diet as: Nitrogen, hydrogen, carbon dioxide, methane, oxygen, and hydrogen sulfide. A joint NASA/USAF study of contaminants associated with the presence of man in a sealed environment has been carried out at the USAF School of Aerospace Medicine (Reference 2). Substances identified during the manned portion of the test but not detected during a prior "background" study of the unmanned test chamber included members of the following chemical groups: Organic acids, aldehydes, aromatic hydrocarbons, esters, ethers, halogen derivatives of ethane, naphthenes, and olefins, as well as methane, propyl mercaptan, and methyl amine.

Sjostrand (1949)* reported measurements of carbon monoxide production by respiration ranging from 15. to 30. milligrams per day. Bogatkov (1961) found CO production by respiration to be 172.8 mg/day for nonsmokers and 410. mg/day for smokers.* Dziedzich (1960) determined a total gaseous hydrocarbon excretion of 230. mg/day while Adamov et al (1962) measured hydrocarbon production at rates up to 1036.8 mg/day.*

Gorban et al (1964) performed 23 individual measurements of gaseous production on 13 healthy men ranging from 20 to 23 years of age. Each subject was confined in a sealed chamber for two periods of time, one of 5 hours and the other of 24 hours duration. At the end of each test the chamber atmosphere and atmospheric water condensate were analyzed quantitatively for impurities. A "background" reading of contaminants produced in the chamber without test subjects was obtained in order to correct the raw data to account only for the presence of man. During each test the total atmospheric pressure and partial pressure of oxygen were actively maintained at terrestrial sea level conditions. The chamber atmospheric temperature was maintained between 20°C and 24°C while the relative humidity varied from 60% to 70%. No information was reported on the diet of the subjects prior to test. Table 1 summarizes the results of Gorban et al.

Data on human metabolic production of gaseous substances indicate wide variability between individual subjects. For purposes of this study the substances and generation rates identified by Gorban et al will be assumed. In addition, the components of human colonic flatus not explicitly identified by Gorban et al but reported by Kirk will be assumed; these consist of methane

*Cited in Reference 3. Metabolic CO production reported in Reference 2 is 11.7 mg/man-day.

TABLE 1. GASEOUS SUBSTANCES PRODUCED BY MAN AS MEASURED BY GORBAN ET AL (1964)

SUBSTANCE	GENERATION RATE $M \pm \sigma$ FOR 24 HOUR TESTS (mg/man-day)	DISTRIBUTION OF SUBSTANCES BASED ON FIVE HOUR EXPOSURE (%)	
		CHAMBER AIR	H ₂ O CONDENSATE
AMMONIA	297.6 \pm 155.6	21.5	78.5
ALDEHYDES	0.59 \pm 0.284	0.	100.
KETONES	232.2 \pm 132.8	40.	60.
MERCAPTANS AND HYDROGEN SULFIDE	4.95 \pm 1.11	0.	100.
FATTY ACIDS	89.45 \pm 11.51	25.7	74.3
CARBON MONOXIDE IN NON-SMOKERS	278.07 \pm 160.8	100.	0.
IN SMOKERS	417.04 \pm 211.5	100.	0.
HYDROCARBONS	504.66 \pm 333.2	100.	0.

NOTE: M AND σ DENOTE MEAN AND STANDARD DEVIATION OF MEASURED VALUES.

(0.548×10^{-4} #/man-day) and hydrogen (0.236×10^{-4} #/man-day). Total production rates are listed in Table 3 for a three-man crew.

An obvious component of human gaseous production, carbon dioxide (~ 2.25 #/man-day), is omitted from the discussion herein primarily because the dangers of high CO_2 concentrations are well known and because the present Cluster design provides for both on-board monitoring of CO_2 partial pressures and CO_2 removal by means of a molecular sieve and/or lithium hydroxide cartridges. Other components of human gaseous wastes, primarily oxygen and nitrogen, are not discussed due to their abundant presence in the nominal cabin atmosphere.

3.0 ACCUMULATION OF METABOLICALLY PRODUCED CONTAMINANTS DURING MISSIONS A AND B

The accumulation of contaminants and their resultant concentrations in the Cluster atmosphere depend on their generation rates and the removal mechanisms available within the spacecraft. In the present Cluster design, some contaminants may be absorbed on activated charcoal filters, all will be partially removed by overboard cabin leakage of the atmosphere, and some will be dissolved in water condensed in the ECS heat exchanger used for humidity control and latent heat removal. Before proceeding further it is useful to consider the quantities of metabolically generated contaminants and the resultant atmospheric concentrations that would result in the absence of any mechanism for contaminant removal (other than for CO_2).

3.1 Contaminant Accumulation in the Absence of Removal Mechanisms

As mentioned previously, Table 3 indicates the production rate of gaseous contaminants produced by a three-man crew. The accumulated quantities of those contaminants in the absence of any removal mechanism is obtained simply as the product of contaminant generation rate and mission duration. The maximum concentration of contaminants is obtained by dividing the total accumulation by the appropriate total pressurized Cluster volume, given in Table 2.*

3.2 Contaminant Accumulation Considering Removal by Overboard Leakage of Cluster Atmosphere

Normal leakage of the spacecraft atmosphere from pressurized volumes of the Cluster will continually remove a

*Pressurized volumes indicated in Table 2 for the CSM, LM A/S, MDA/STS, Airlock and Workshop are those given in References 4 through 8, respectively.

TABLE 2. PRESSURIZED VOLUMES OF THE AAP CLUSTER

MODULE	MISSION A	MISSION B
CSM	365. ft ³	365. ft ³
LM A/S	---	180.
MDA/STS	1140.	1140.
AIRLOCK	294.	294.
WORKSHOP	10,400.	10,400.
TOTAL	12,199.ft ³ (346.Meters ³)	12,379.ft ³ (351.Meters ³)

TABLE 3. GASEOUS CONTAMINATION PRODUCED BY A THREE-MAN CREW IN AAP 1-4
ASSUMING NO CONTAMINANT REMOVAL

SUBSTANCE	GENERATION RATE (mg./day) M (M+σ)	MAXIMUM CONCENTRATION (mg/m ³)	
		MISSION A (28 days)	MISSION B (56 days)
AMMONIA	892.8 (1359.6)	72.2 (110.)	142. (216.)
ALDEHYDES	1.77 (2.62)	0.143 (0.212)	0.283 (0.419)
KETONES	696.6 (1095.0)	56.4 (88.5)	111. (175.)
MERCAPTANS AND HYDROGEN SULFIDE	14.85 (18.2)	1.20 (1.47)	2.37 (2.90)
FATTY ACIDS	268.4 (302.9)	21.8 (24.5)	42.9 (48.4)
CARBON MONOXIDE NONSMOKERS	834.21 (1317.)	67.5 (106.5)	133. (210.)
SMOKERS	1251. (1886.)	101. (152.)	200. (301.)
HYDROCARBONS	1514. (2514.)	123. (204.)	242. (401.)
METHANE (IN FLATUS)	74.5	6.03	11.9
HYDROGEN (IN FLATUS)	32.1	2.60	5.13

NOTE: (1) M = MEAN GENERATION RATE
(2) σ = STANDARD DEVIATION OF GENERATION RATE
(3) CARBON DIOXIDE OMITTED FROM TABLE.

fraction of all gaseous contaminants present. The actual rate of leakage from spacecraft modules cannot be accurately predicted; however, atmospheric leak rates of Cluster components have been budgeted for purposes of defining the quantities of gaseous consumables needed on AAP 1 - 4 (Reference 9). These leak-rates are shown in Table 4. Contaminant removal rates will be proportional to the actual atmospheric leak rate; in the event that actual leak rates are less than nominal, deliberate overboard venting of atmospheric gases, up to the nominal leakage rate, could be employed for contaminant removal if that appeared necessary or desirable.

The concentration of a given contaminant in the spacecraft atmosphere under equilibrium or steady state conditions can be found as follows. Let R_i = the generation rate of contaminant i ; L = leakage rate of the nominal atmosphere; m_i and M = mass of contaminant i and nominal atmosphere leaked overboard in a given interval of time. Then, Since contaminant generation and leak rates are equal under steady-state conditions,

$$1) \quad \frac{m_i}{M} = \frac{R_i}{L}.$$

The contaminant and nominal atmosphere exist in the same ratio, m_i/M , in the spacecraft interior as in the gas leaked overboard.

Thus, the ratio of the equilibrium densities of contaminant and nominal atmosphere within the spacecraft (C_i/D) equals the ratio m_i/M . Therefore, substituting C_i/D for m_i/M in equation (1) yields

$$2) \quad C_i = \frac{R_i}{L} D.$$

It should be noted that expression (2) neglects the possible removal of contaminants by adsorption of charcoal filters and/or by dissolving in water condensate in a latent heat exchanger, both of which removal mechanisms exist in the Cluster environmental control system (specifically, in the Airlock).

The nominal Cluster cabin atmosphere is approximately 74% oxygen and 26% nitrogen at a total pressure of 5 psia; the nominal average temperature will be approximately 70°F (Reference 9). The density of oxygen at 3.7 psia and 70°F is 0.0208#/ft³; the

density of nitrogen at 1.3 psia and 70°F is 0.00640#/ft³. Thus the nominal atmospheric density, D, is 0.0272#/ft³. Equilibrium concentrations of contaminants generated by a three-man crew and partially removed by overboard leakage are shown in Table 5 as calculated from equation (2) with D = 0.0272#/ft³ (4.35×10^5 mg/m³) and L = 20.55#/day (93.0×10^5 mg/day), 27.75#/day ($126. \times 10^5$ mg/day) for Missions A, B respectively.

TABLE 4. MAXIMUM CLUSTER LEAKAGE CONSISTENT
WITH CONSUMABLES CAPACITY FOR NOMINAL
AAP MISSIONS*

COMPONENT	MISSION A (#/DAY)	MISSION B (#/DAY)
CSM	4.8	4.8
CSM/MDA INTERFACE	2.4	2.4
LM/ATM	---	4.8
LM/MDA INTERFACE	---	2.4
MDA/STS	4.8	4.8
AIRLOCK MODULE	1.0	1.0
MOLECULAR SIEVE**	2.75	2.75
WORKSHOP	4.8	4.8
TOTAL	20.55#/DAY (93. x 10 ⁵ mg/DAY)	27.75#/DAY (126. x 10 ⁵ mg/DAY)

*Based on Reference 9.

**Normal operation of the molecular sieve dumps 1.ft³,
of 40°F, 5 psia cabin atmosphere overboard every fifteen minutes.

TABLE 5.

GASEOUS CONTAMINATION PRODUCED BY A THREE MAN CREW IN AAP 1-4
ASSUMING CONTAMINANT REMOVAL BY CABIN ATMOSPHERIC LEAKAGE

SUBSTANCE	GENERATION RATE (mg/Day) M (M+σ)	EQUILIBRIUM CONCENTRATION (mg/m ³)	
		MISSION A	MISSION B
AMMONIA	892.8 (1359.6)	41.7 (63.5)	30.8 (46.9)
ALDEHYDES	1.77 (2.62)	0.0888 (0.123)	0.0610 (0.0905)
KETONES	696.6 (1095.0)	32.6 (51.3)	24.0 (37.8)
MERCAPTANS AND HYDROGEN SULFIDE	14.85 (18.2)	0.695 (0.851)	0.513 (0.629)
FATTY ACIDS	268.4 (302.9)	12.6 (14.2)	9.28 (10.4)
CARBON MONOXIDE NONSMOKERS	834.21 (1317.)	39.0 (61.6)	28.8 (45.5)
SMOKERS	1251. (1886.)	58.6 (88.3)	43.3 (65.0)
HYDROCARBONS	1514. (2514.)	70.9 (118.)	52.3 (86.7)
METHANE (IN FLATUS)	74.5	3.48	2.57
HYDROGEN (IN FLATUS)	32.1	1.50	1.11

NOTE: (1) M = MEAN GENERATION RATE
(2) σ = STANDARD DEVIATION OF GENERATION RATE
(3) CARBON DIOXIDE OMITTED FROM TABLE.

4.0 PHYSIOLOGICAL EFFECTS AND ALLOWABLE CONCENTRATIONS OF CONTAMINANTS

The acute physiological effects of exposure to certain contaminants produced by man are well known; the effect of continuous exposures for periods of one to two months is far less certain. The synergistic physiological effect of two or more contaminants present simultaneously is virtually unknown. This section reviews certain known physiological reactions to contaminants, described above, as well as maximum trace contaminant criteria.

4.1 Carbon Monoxide

Carbon monoxide creates a physiological effect upon human tissue by combining with hemoglobin in the blood and thereby reducing the normal supply of oxygen throughout the body. It is only slightly soluble in water (Table 1) which renders its removal by dissolving in humidity-condensate within the Cluster ECS a negligible factor; it is not appreciably adsorbed by charcoal filters (Reference 10). The only mechanism for CO removal inherent in the present Cluster design is overboard leakage of the atmosphere.

Concentrations of carbon monoxide found in the terrestrial atmosphere vary considerably. Table 6 indicates the results of CO surveys made in Cincinnati, Detroit, and Los Angeles; median CO concentrations of urban areas range approximately from 5. to 15. mg/m³. Long duration continuous exposures to higher concentrations have however been experienced without observed ill effects. One hundred eight subjects, age 17 to 37 were exposed to an average CO concentration of 50. mg/m³ for a continuous duration of 72 days in an operational nuclear submarine; observation of general health, vital signs, blood cells, exercise tolerance, caloric requirements, and dietary habits showed no harmful effects during or shortly after exposure (Reference 14).

During the Navy's Operation Hideout, 23 subjects were exposed to CO concentrations > 28. mg/m³ for over 22 consecutive days, including 18 days at > 55 mg/m³ of CO; subjective complaints during exposure to > 110 mg/m³ were found to have a small statistical significance when compared with complaints recorded during a control period (Reference 15). Operations conducted with Sealab II resulted in continuous exposures of 15 days duration for 3 crews of ten men each; CO concentrations during the three

*References 11 - 13.

TABLE 6. CO CONCENTRATIONS IN THE TERRESTRIAL ATMOSPHERE

AUTHORS	STUDY LOCATION	CO CONCENTRATION (mg/m ³)	SAMPLING DURATION
Cholak et al (Reference 10)	Cincinnati	Rural 5.7 +11.4 - 5.7	24 Months
		Industrial 10.8 +52. -10.8	24 Months
		All Areas 8.55	24 Months
		Business 10.3 104. -10.3	21 Weeks
Clayton et al (Reference 11)	Detroit	Residential 2.28 +30.8 - 2.28	18 Weeks
Hamming et al (Reference 12)	Los Angeles	L. A. Basin 3.42 to 13.7	Monthly Average
		Downtown 4.56 to 14.8	Monthly Average

operational periods were 5.7 to 34. mg/m³ (median 20. mg/m³), > 34 mg/m³, and 17. to 34. mg/m³ (median 25. mg/m³) respectively (Reference 16).

A commonly accepted industrial exposure limit for CO is 55 mg/m³; this limit is of course based on an intermittent exposure corresponding to industrial work shifts of 8 hours/day, 5 days/week and is thus not directly applicable to continuous chronic exposures (Reference 17). Recommended maximum concentrations for continuous exposure to CO vary widely. The U. S. Navy is currently studying a recommendation for a maximum CO concentration of 28. mg/m³ applicable to 90-day continuous exposures in nuclear submarines (Reference 18).

MORL studies have established maximum concentration limits for CO and other contaminants by arbitrarily reducing Industrial Threshold Values (TLV's) by one order of magnitude (Reference 19).^{*} Soviet authors have in general proved to be more conservative in recommending maximum exposure levels than their American counterparts: Lebedinskiy et al (1964) recommend a maximum CO concentration of 3. to 5. mg/m³ for continuous exposures of four or more months (Reference 20).

Predicted levels of CO contamination on AAP 1-4, summarized from Tables 3 and 5 are as follows. The maximum concentration of CO assuming accumulation of all CO generated by a crew of nonsmokers is:

	<u>Mission A</u>	<u>Mission B</u>
Mean Value (M)	67.5 mg/m ³	133. mg/m ³
One Sigma Value (M+σ)	106.5 mg/m ³	210. mg/m ³

These values of CO concentration, based on CO generation rates measured by Gorban et al, exceed the recommended values cited above. If nominal overboard leak rates of the cabin atmos-

^{*}Current (1967) TLV's are given in Reference 17.

where are maintained during flight, the following equilibrium concentrations of CO will be attained:

	<u>Mission A</u>	<u>Mission B</u>
Mean Value (M)	39.0 mg/m ³	28.8 mg/m ³
One Sigma Value (M+σ)	61.6 mg/m ³	45.5 mg/m ³

Mission A concentrations of 40. to 60 mg/m³ are comparable to the maximum CO concentration (50 mg/m³) for which human exposures have been shown to be tolerable. Both Mission A and Mission B equilibrium concentrations exceed the Navy's tentative limit of 28. mg/m³ for continuous 30-day exposures to CO.

Although it is not the purpose of this memorandum to discuss atmospheric contaminants arising from sources other than the crew, it is worth noting that:

- a) Experimental evidence indicates that CO outgassed from many nonmetallic materials appears to be generated continuously for periods up to at least 90 days despite curing (Reference 21).
- b) MSC nonmetallic-material guidelines permit CO originating from S/C materials to achieve concentrations as high as 28. mg/m³ (Reference 22).

If the CO generated by outgassing from non-metallic materials is considered in combination with CO generated by the crew, total CO concentrations may appreciably exceed levels beyond which some degradation in crew performance may occur.

4.2 Ammonia

Ammonia irritates mucous membranes after short duration exposures to concentrations of 70. mg/m³ (100 ppm); appreciably higher concentrations may damage mucous surfaces (Reference 23). The maximum concentration in the Cluster, assuming accumulation of all ammonia produced by the crew, is given in Table 3 as:

	<u>Mission A</u>	<u>Mission B</u>
Mean Value (M)	72.2 mg/m ³	142. mg/m ³
One Sigma Value (M+σ)	110. mg/m ³	216. mg/m ³

Each of these values exceeds the maximum industrial exposure limit (TLV) of 35. mg/m³ which, again, is based on intermittent rather than continuous exposure (Reference 17).

Equilibrium concentrations of ammonia in the Cluster, assuming nominal overboard leakage of the atmosphere, are:

	<u>Mission A</u>	<u>Mission B</u>
Mean Value (M)	41.7 mg/m ³	30.8 mg/m ³
One Sigma Value (M+σ)	63.5 mg/m ³	46.9 mg/m ³

The one sigma value for Mission A (63.5 mg/m³) is comparable to the concentration at which mucous membrane irritation can be expected during a short duration exposure. Chronic exposure effects are not known.

The U. S. Navy's tentative maximum concentration of NH₃ for a continuous exposure of 90 days duration is 17.5 mg/m³ (Reference 18), which is clearly exceeded by the equilibrium concentrations shown above. Some removal of ammonia from the atmosphere by dissolving in humidity-condensate is to be anticipated from the high solubility of NH₃ in water and from the results of Gorban *et al* (see Table 1). The extent to which this removal mechanism can be relied on in the Cluster is conjectural; however, if the 78.5% removal of NH₃ by condensate noted in Reference 2 is applicable to the Cluster as well as removal by nominal leakage, the following hypothetical equilibrium concentrations of ammonia will occur:

	<u>Mission A</u>	<u>Mission B</u>
Mean Value (M)	32.7 mg/m ³	24.2 mg/m ³
One Sigma Value (M+σ)	50.0 mg/m ³	36.8 mg/m ³

These concentrations are below the level at which acute effects are anticipated; they remain, however above the U. S. Navy tentative criterion for a 90-day exposure. One sigma values exceed the industrial TLV.

4.3 Other Contaminants

With the exception of hydrogen and methane, the contaminants listed in Tables 3 and 5 that have not been discussed are identified only by their chemical class, e.g., aldehydes, ketones, fatty acids, and not as individual substances. Known physiological effects differ widely among members of a given chemical class; it is thus not realistic to attempt an assessment of the physiological effects of aldehydes, ketones, etc., as such.

Hydrogen and methane are not thought to be toxic in the concentrations calculated above (maximum one sigma values of 5.13 mg/m^3 and 11.9 mg/m^3 , respectively, assuming accumulation of all H_2 and CH_4 generated by the crew). The tentative U. S. Naval maximum concentrations for a 90-day continuous exposure to H_2 and CH_4 are $245. \text{ mg/m}^3$ and $3260. \text{ mg/m}^3$, respectively (Reference 18).

5.0 CONTAMINANT REMOVAL SYSTEMS

As stated previously, gaseous contaminants will be to some extent removed from the Cluster by overboard leakage of the atmosphere, by dissolving in humidity condensate in the Airlock ECS's latent heat exchanger, and by adsorption on charcoal filters which are also part of the Airlock ECS.

Catalytic oxidizers have been in use aboard nuclear submarines for several years specifically to burn carbon monoxide and hydrogen to water and carbon dioxide. (Hydrogen in submarine atmospheres is generated primarily by batteries; carbon monoxide is generated in appreciable amounts by smoking which is permitted even in long duration, continuously submerged missions on nuclear submarines.) A by-product of the use of catalytic burners is that in addition to CO and H_2 , higher hydrocarbons are also broken down, from which the catalytic oxidizers derive their nickname of "trash-burners." The trash-burning function is obviously useful, particularly since the effects of the large number of hydrocarbons that may be present and the synergistic effects of those substances on man are unknown for continuous exposures of the duration of Missions A and B. Catalytic burners, however, are not without problems of their own. During off-nominal operation at temperatures lower than anticipated, incomplete combustion of higher hydrocarbons may result in the transformation of nontoxic substances to toxic substances. This potential for trouble has been unintentionally demonstrated aboard nuclear submarines and in the MESA experiments carried out by Boeing (References 24 - 26). In the latter case, trichloroethylene which was introduced into a space cabin simulator as a cleaning agent prior to manned operations, was transformed to dichloroacetylene in a catalytic burner operating below design temperature during manned operations. The crew's physical reaction (nausea, itching eyes, headaches, etc.) resulted in a mission abort after four days. Known symptoms of the highly toxic dichloroacetylene indicated a near-fatal dose had been received prior to the abort.

6.0 CONTAMINANT CONTROL STRATEGIES

A number of techniques are available for controlling trace contaminant hazards in the Cluster. These include:

1. Increased allotment of atmospheric gases for over-board leakage
2. Provision of sensing devices such as gas chromatographs to detect and monitor concentrations of anticipated contaminants
3. Provision of a catalytic burner as part of the ECS
4. Reliance on contaminant removal mechanisms already in the Cluster design and man's ability to tolerate or adapt to contaminants; this can be combined with an option to rapidly abort Mission A or B in the event of a noticeably adverse reaction by the crew
5. A combination of two or more of the preceding possibilities.

Each of the above options has its own advantages and disadvantages. Deliberately increasing cabin leakage would reduce the equilibrium concentrations of all gaseous contaminants; it would also increase the weight of some or all payloads of AAP 1 - 4, or reduce the nominal durations of Missions A and B. Provision of sensing devices requires the addition of expensive hardware while providing only a warning to: dump a portion of the atmosphere, increase leakage, abort the mission, etc. Addition of a catalytic burner provides positive control of CO, H₂ and hydrocarbons during nominal operation; it is however not necessarily "fail-safe" during off-nominal performance. The fourth possibility - to rely on contaminant control mechanisms already included in the Cluster design until noticeable symptoms appear in the crew may compromise the safety of the astronauts as well as mission success. Detailed study of the available alternatives is required before an optimum strategy can be defined.

7.0 CONCLUSIONS

An analysis of the hazard resulting from contamination of the Cluster atmosphere by gaseous substances given off by man has been presented. Concentrations of contaminants identified

by Kirk and by Gorban et al have been computed for AAP Missions A and B assuming (1) no cabin leakage or other removal mechanisms and (2) nominal leakage from the Cluster. With the exception of ammonia, CO, H₂ and CH₄, contaminant rates are known only for certain chemical classes. No general statement about the toxicity of classes is possible; therefore these groups were not considered further than to specify their predicted concentrations. H₂ and CH₄ in acute exposures are not toxic, although no information on possibly toxic effects resulting from a one or two-month exposure in combination with an O₂/N₂ atmosphere at 5 psia and other possible atmospheric contaminants is available. Experience with nuclear submarines suggests that the calculated concentrations for H₂ and CH₄ are, by themselves, not a toxicological hazard. Calculated ammonia concentrations based on removal only by cabin leakage are possibly serious as an acute irritant. Some removal (possibly ~ 79%) can be expected by NH₃ dissolving in water condensed in the Airlock ECS latent heat exchanger; nevertheless, the chronic exposure to calculated levels of NH₃ may be excessive where compared with U. S. Naval submarine criteria.

Carbon monoxide may be a potential problem; Calculated Mission A concentrations of 40. to 60. mg/m³, based on CO generation rates measured by Gorban et al and CO removal by overboard leakage, are comparable to the maximum CO concentration (50. mg/m³) for which continuous human exposures have been shown to be tolerable without reported performance degradation. If the CO generated by outgassing from nonmetallic materials is considered, total CO concentrations may appreciably exceed levels beyond which some degradation in crew performance may be expected. A strategy for dealing with CO contamination of the Cluster atmosphere on Missions A and B may therefore be desirable. Available alternatives include one or more of the following: Provision of more O₂/N₂ to permit higher leak rates and, thus, lower CO equilibrium concentrations; provision of CO sensors coupled with cabin-dump or mission abort criteria; reliance on inherent removal mechanisms in the Cluster, i.e., nominal leakage; or provision of a catalytic burner. Each of these options has its own advantages and disadvantages as described previously. Detailed study is required to determine the optimum strategy for dealing with the CO contam-

ination hazard as well as the possible hazards arising from other atmospheric contaminants.*

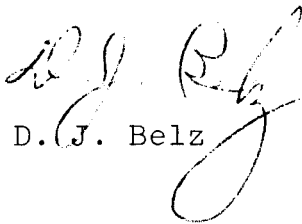
Finally it should be noted that the metabolically generated component of atmospheric contamination has been dealt with above not because it is expected to be the major component, but because it is amenable to a quantitative analysis. Although the contribution of nonmetallic materials to atmospheric contamination may easily exceed that due to the crew, it is not yet possible to quantify the extent of that contribution.

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Attachments


D.(J. Belz

*The wide variation in reported rates of CO generation by humans introduces considerable uncertainty into any assessment of the CO hazard for early AAP spacecraft. CO generation rates employed in the present memorandum have been taken from the "pessimistic" end of the reported range; calculations based on the lowest reported generation rates will indicate equilibrium concentrations of CO appreciably lower than the values discussed in Section 4.1 (see Attachment).

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CO CONTAMINATION OF AAP MISSION A AND B ATMOSPHERES
 BY A THREE-MAN CREW (ASSUMING REMOVAL BY CABIN LEAKAGE)
 BASED ON DATA OF CONKLE ET AL (1967)

CO GENERATION RATE (mg/day)	MAXIMUM CO CONCENTRATION (mg/m ³)	
	MISSION A (28 Days)	MISSION B (56 Days)
35.1	1.64	1.21